KATHOLIEKE UNIVERSITEIT LEUVEN

Nature of the Magnetic Fields in Magnetic Clouds

Are all CMEs flux ropes?

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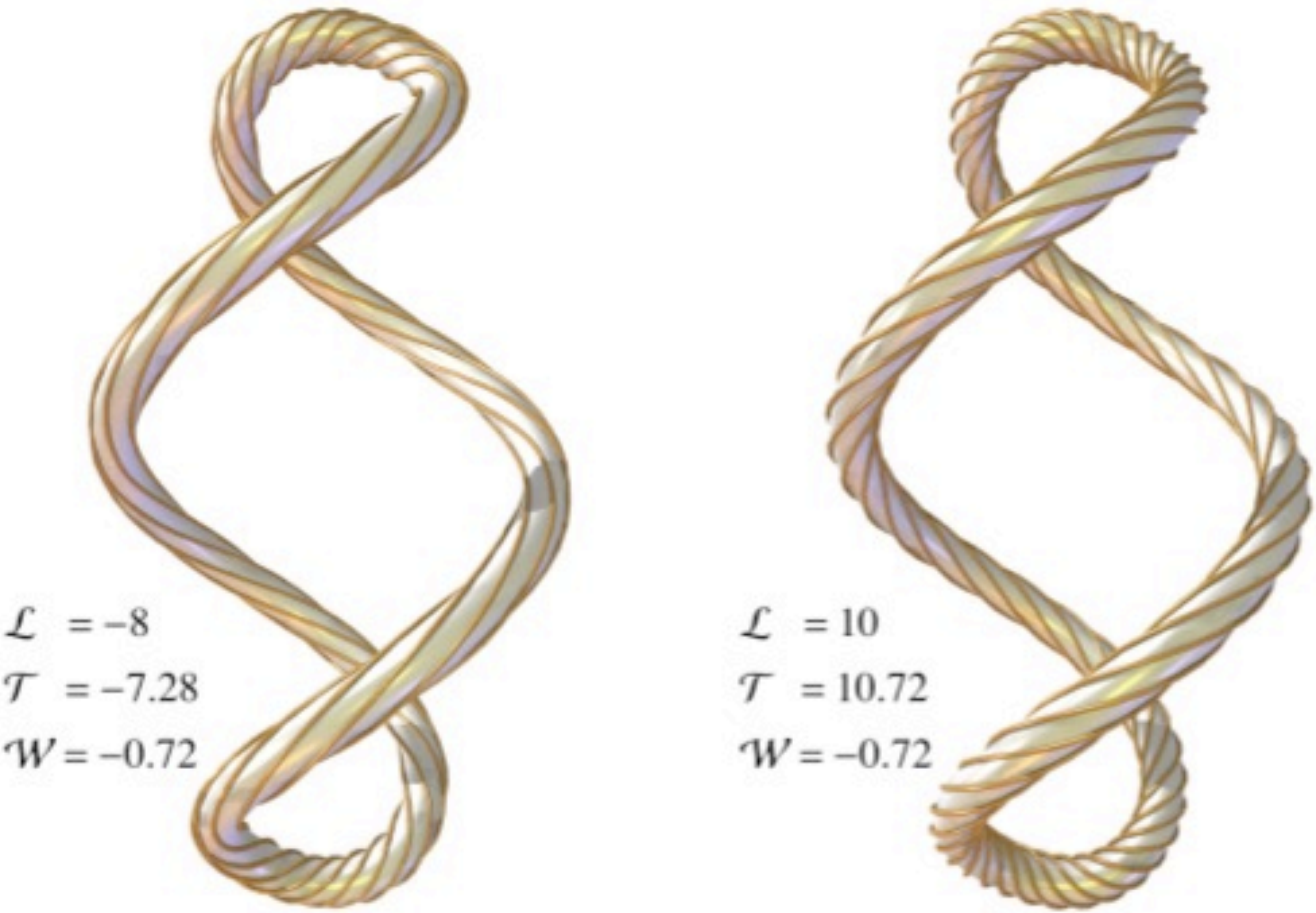
Writhe vs. Twist (Berger & Prior :2006)



Background

Magnetic clouds:

* 1/3 of ICME
* low temperature,
* low density,
* decreasing speed,
* and low plasma beta: $\beta \ll 1$,
* **a strong, smoothly rotating magnetic field**

Data

Simulations:

* Jacobs et al (2009)

  Writhed magnetic field lines

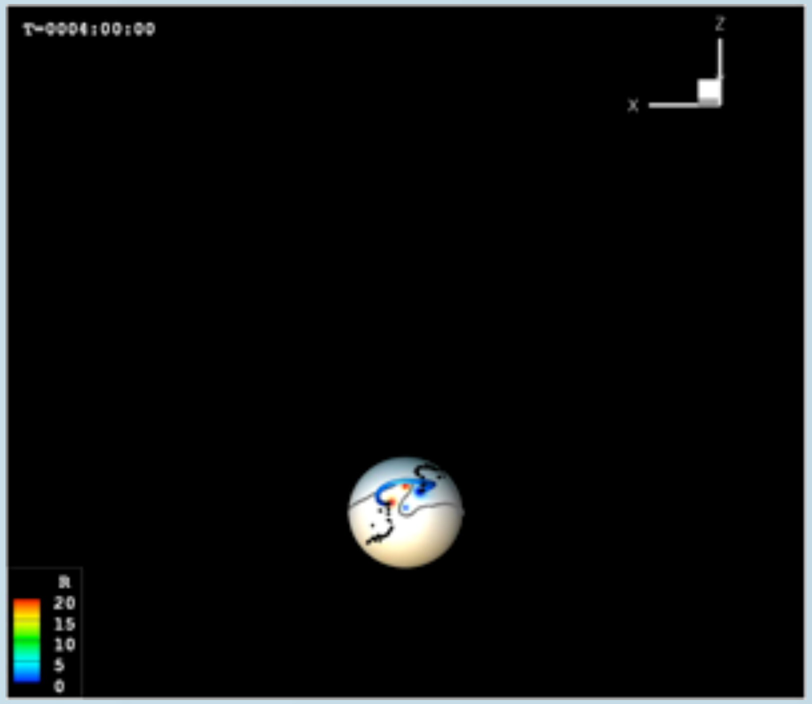
  Dipole

Differences:
1- Topology of the active region
2- Strength of the overlying magnetic field,
3- Pressure/density/velocity distribution in the solar wind.
4- Different speed of the MC

* Jacobs (PC)

  Writhed magnetic field lines

  Quadropole



Jacobs et al (2009)

Data

Simulations:

* Jacobs et al (2009)

  Writhed magnetic field lines

  Dipole

Differences:
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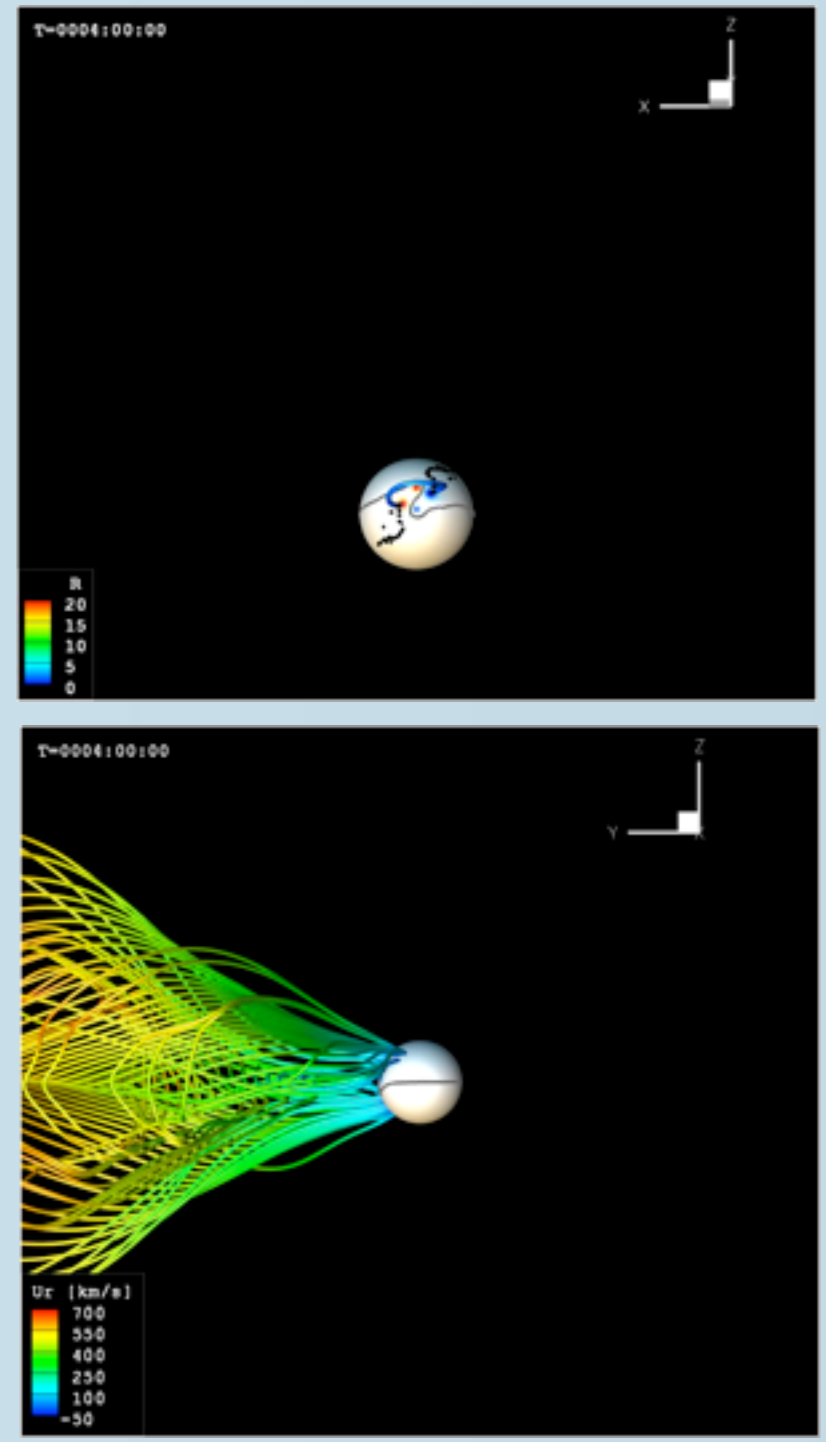
  Quadropole



Jacobs et al (2009)

Data

* Jacobs et al (2009)

  3 synthetic satellites at 15Rs

  (0,15,0) (2,15,0) (-2,15,0)

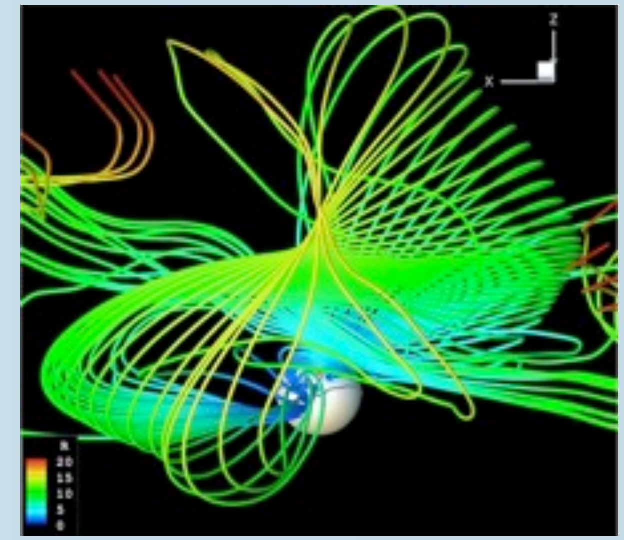
* Jacobs (PC) (Quadruple case)

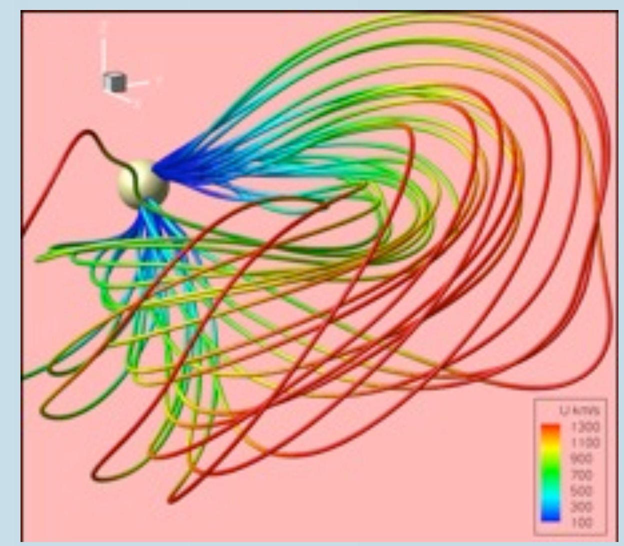
  3 synthetic satellites at 15Rs

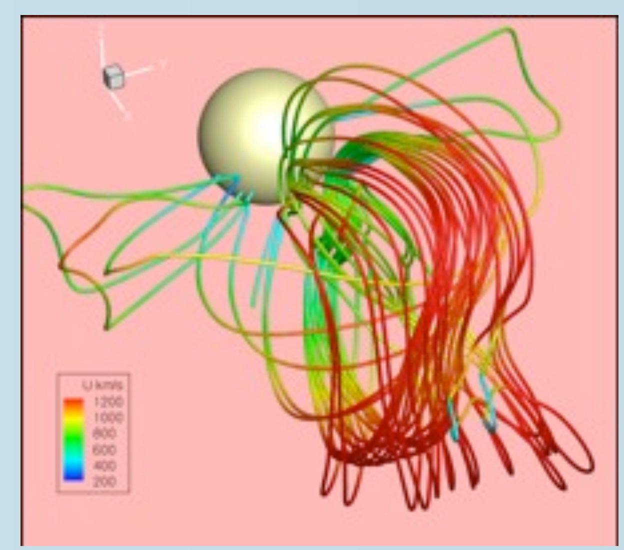
  (15,0,0) (13,7.5,0) (13,-7.5,0)

  3 synthetic satellites at 70Rs

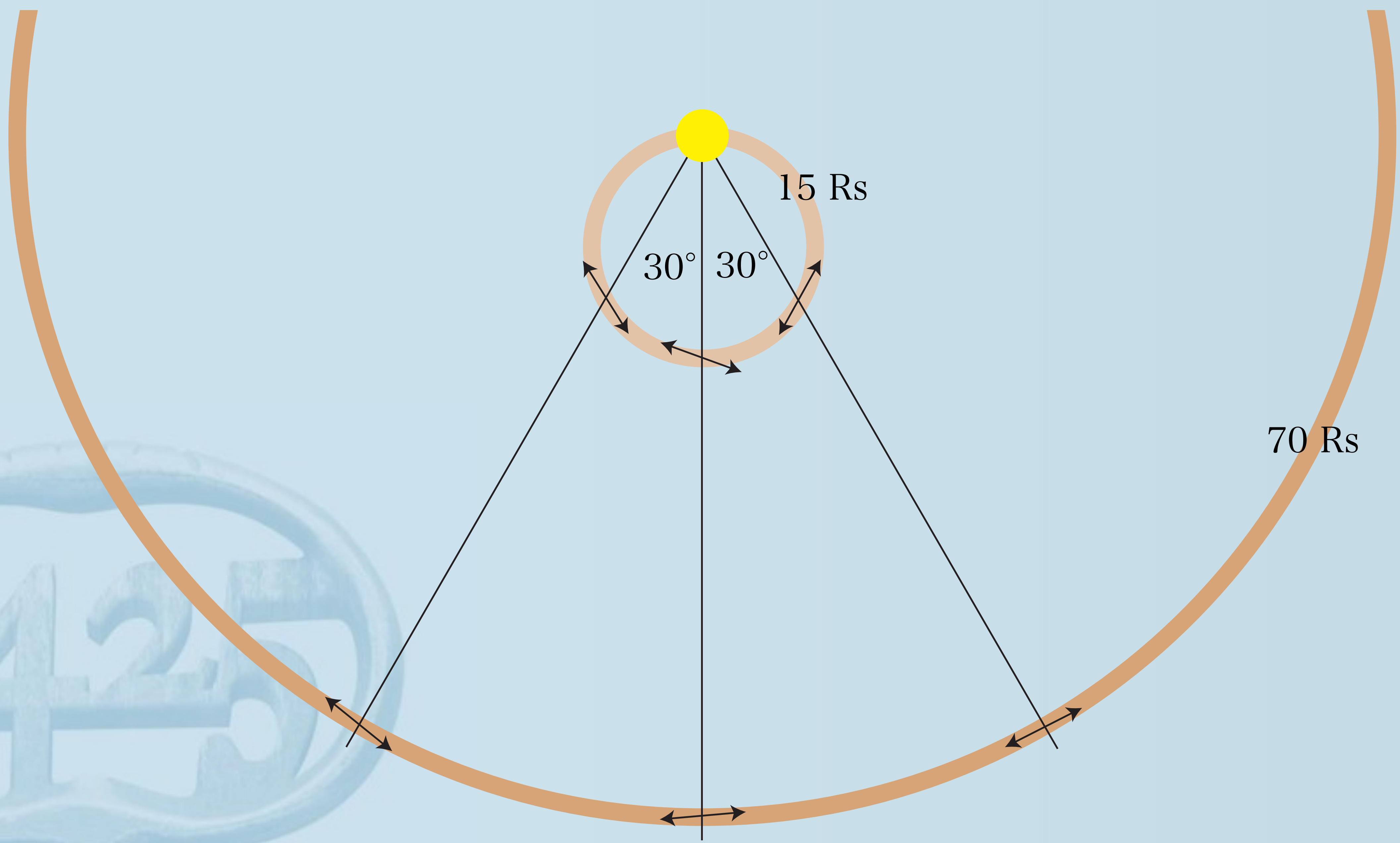
  (70,0,0) (60.6,35,0) (60.6,-35,0)







Data: Jacobs (PC)



Magnetic field Reconstruction Methods

* Grad-Shafranov

* Force Free & Variations

  -Linear FF

  -Non-linear FF

* Non Force-Free Elliptical

* Torus

$$\text{MHSE}: \ \nabla \mathbf{p} = \mathbf{j} \times \mathbf{B}$$

$$\nabla.\mathbf{B}=0, \ \nabla \times \mathbf{B} = \mu_\circ \mathbf{j}$$

$$\Rightarrow \partial/\partial z \approx 0$$

$$\boxed{\frac{\partial^2 A}{\partial x^2} + \frac{\partial^2 A}{\partial y^2} = -\mu_0 \frac{d}{dA}\left(p + B_z^2/2\mu_0\right),}$$

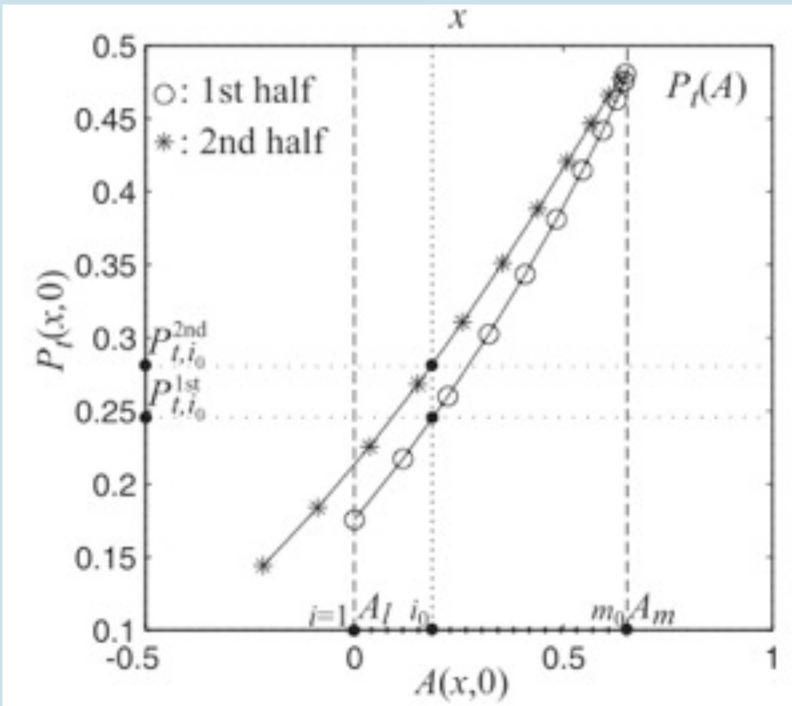
$$\mathbf{A} = \mathrm{A}(x, y)\hat{\mathbf{z}}$$

$$\mathbf{B}=[\partial \mathbf{A}/\partial \mathbf{y}, -\partial \mathbf{A}/\partial \mathbf{x}, \mathbf{B}_z(\mathbf{A})]$$

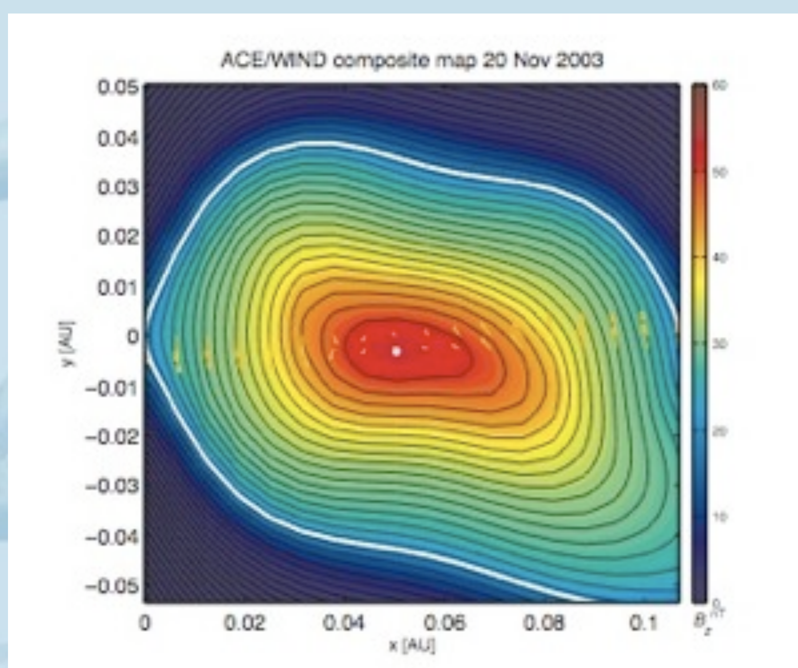
$$\Rightarrow \mathbf{p} = \mathbf{p}(\mathbf{A}), \mathbf{B}_z = \mathbf{B}_z(\mathbf{A}) \text{ and}$$

$$P_t(A) = p + B_z^2/2\mu_0$$

Magnetic field Reconstruction Methods



Hu & Sonnerup (2002)



Moestl et al. (2009)

$$\mathbf{MHSE:}\ \nabla \mathbf{p} = \mathbf{j} \times \mathbf{B}$$

$$\nabla.\mathbf{B}=0,\ \nabla \times \mathbf{B} = \mu_o \mathbf{j}$$

$$\Rightarrow \partial/\partial \mathbf{z} \approx 0$$

$$\boxed{\frac{\partial^2 A}{\partial x^2} + \frac{\partial^2 A}{\partial y^2} = -\mu_0 \frac{d}{dA}\left(p + B_z^2/2\mu_0\right),}$$

$$\mathbf{A} = \mathrm{A}(x, y)\hat{\mathbf{z}}$$

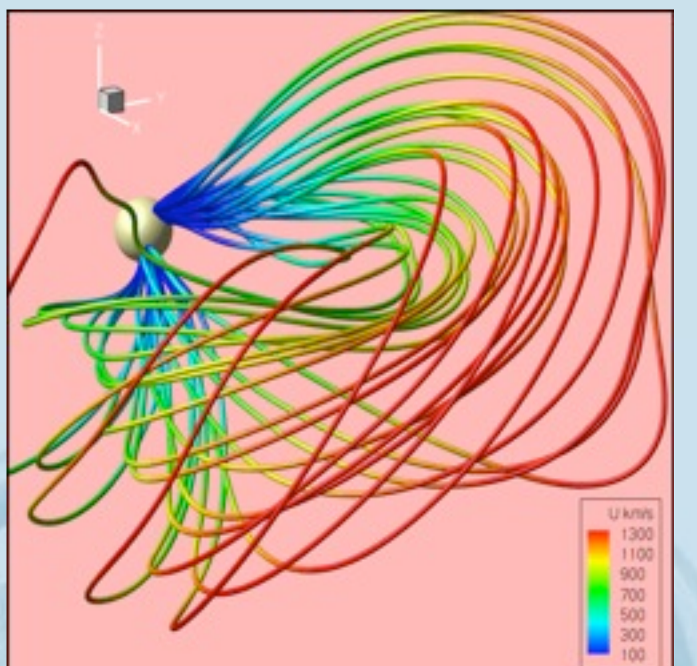
$$\mathbf{B} = [\partial \mathbf{A}/\partial \mathbf{y},\ -\partial \mathbf{A}/\partial \mathbf{x},\ \mathbf{B_z}(\mathbf{A})]$$

$$\Rightarrow \mathbf{p} = \mathbf{p}(\mathbf{A}),\ \mathbf{B_z} = \mathbf{B_z}(\mathbf{A})\ \mathbf{and}$$

$$P_t(A) = p + B_z^2/2\mu_0$$

Project

Simulation Data of writhed magnetic field lines

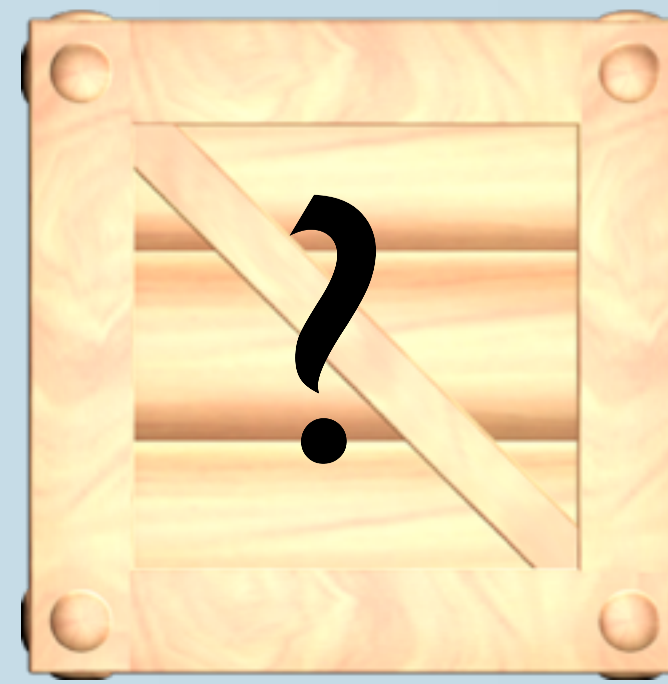


→

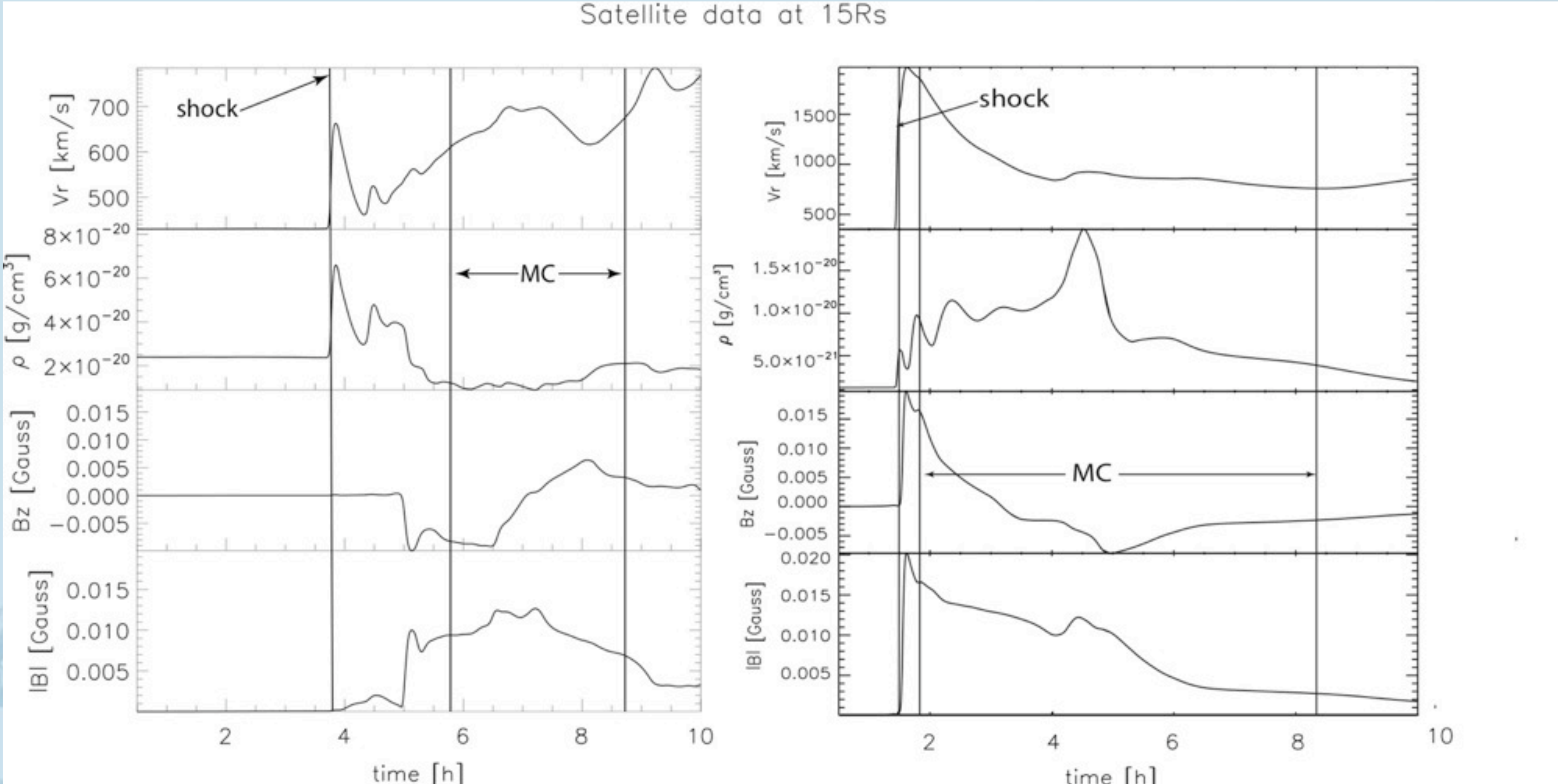
Magnetic field reconstruction GS Code

→

Twisted flux rope or writhed field line?



The Magnetic Clouds

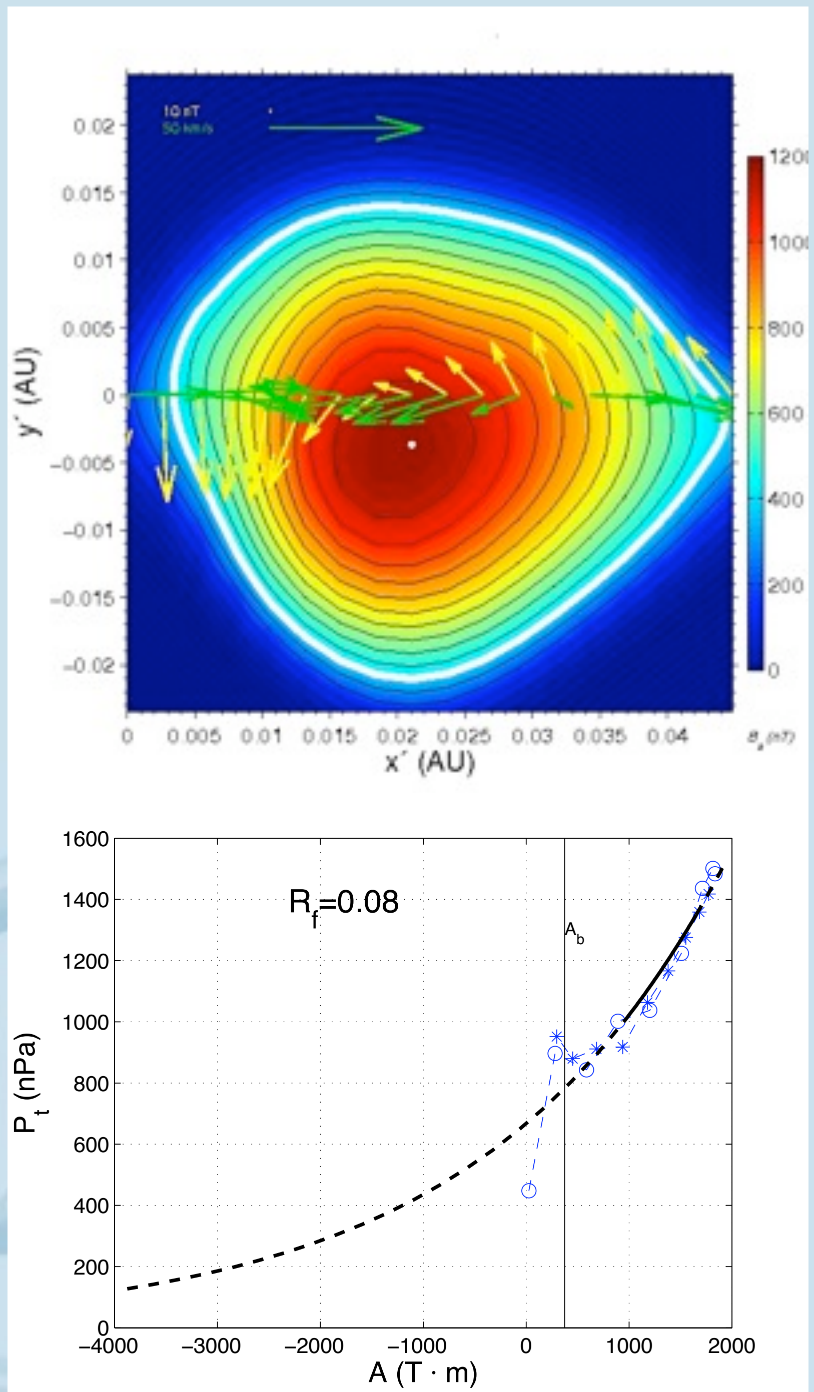


Dipolar case

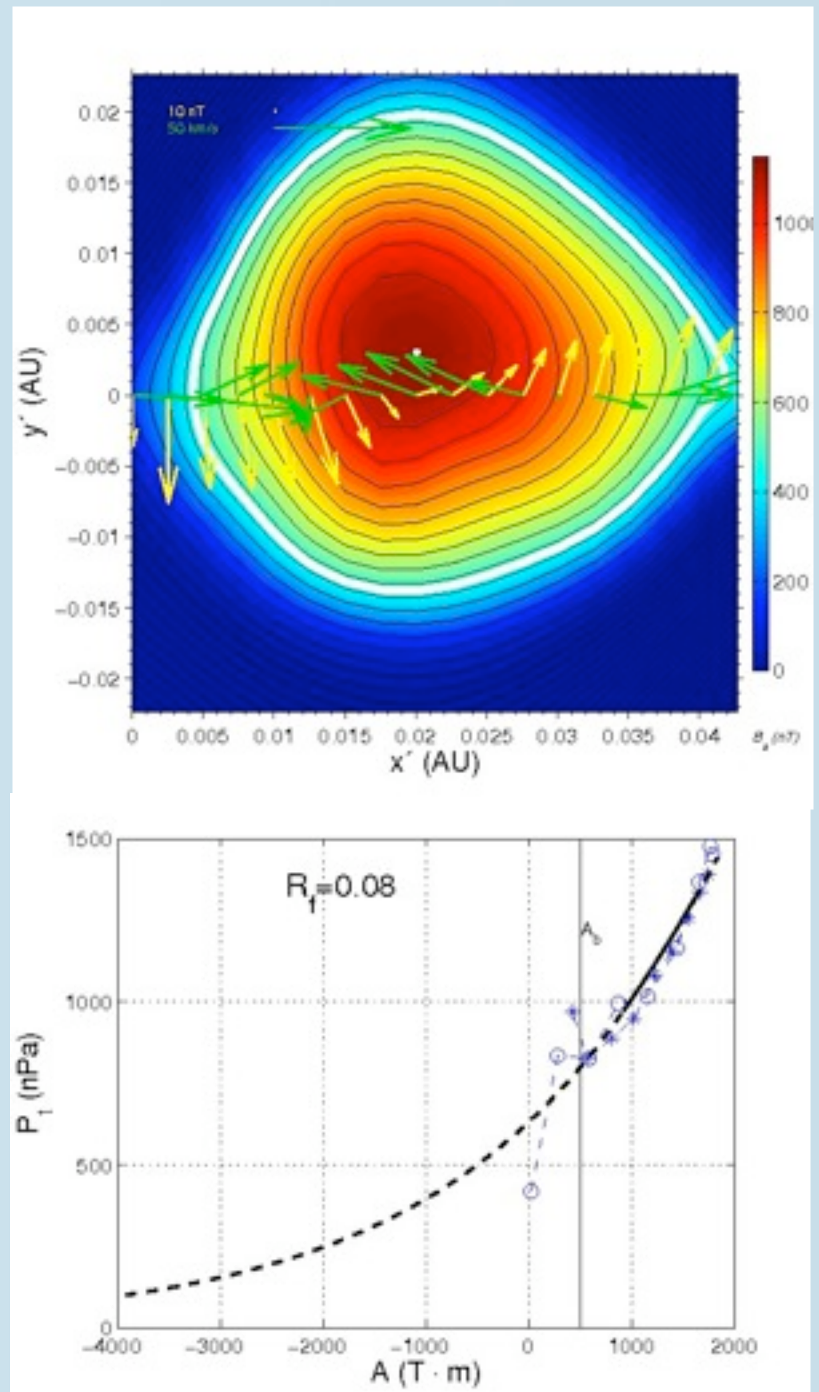
Quadrupolar case

Results

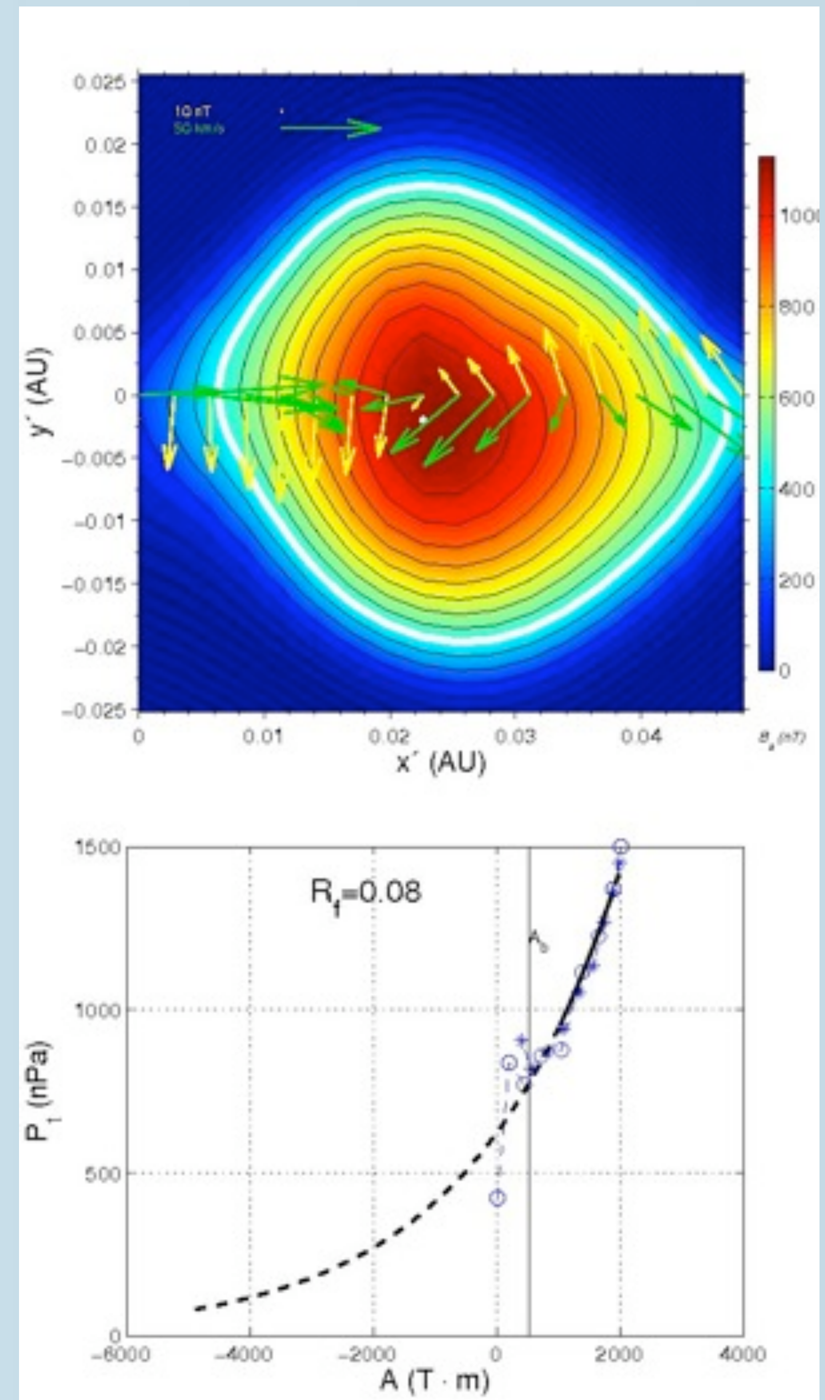
MF Reconstruction of Jacobs et al. (2009):



long: 109.07, lat: -6.45



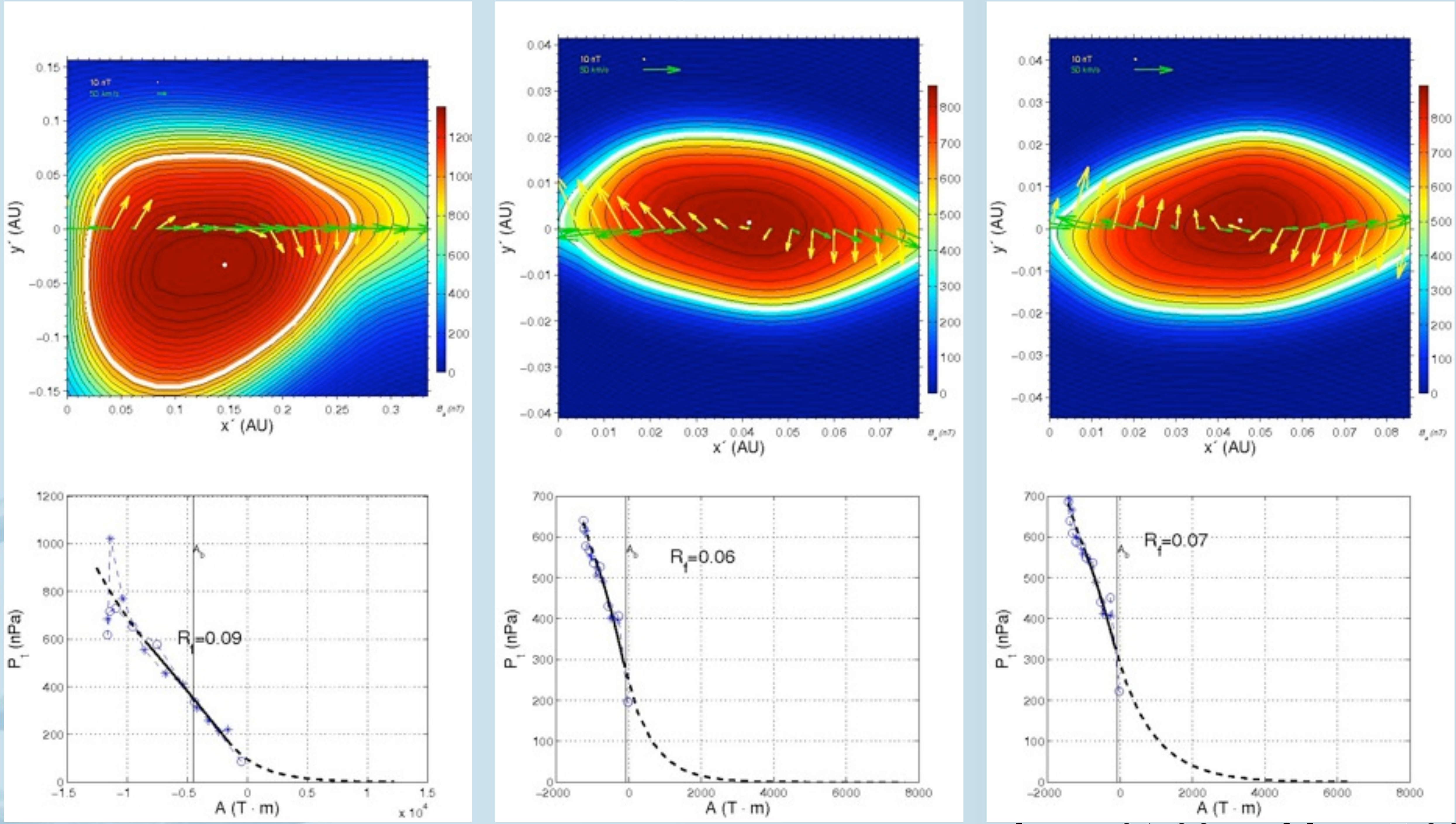
long: 70.50 and lat: -6.01



long 111.79 and lat -10.23

Results

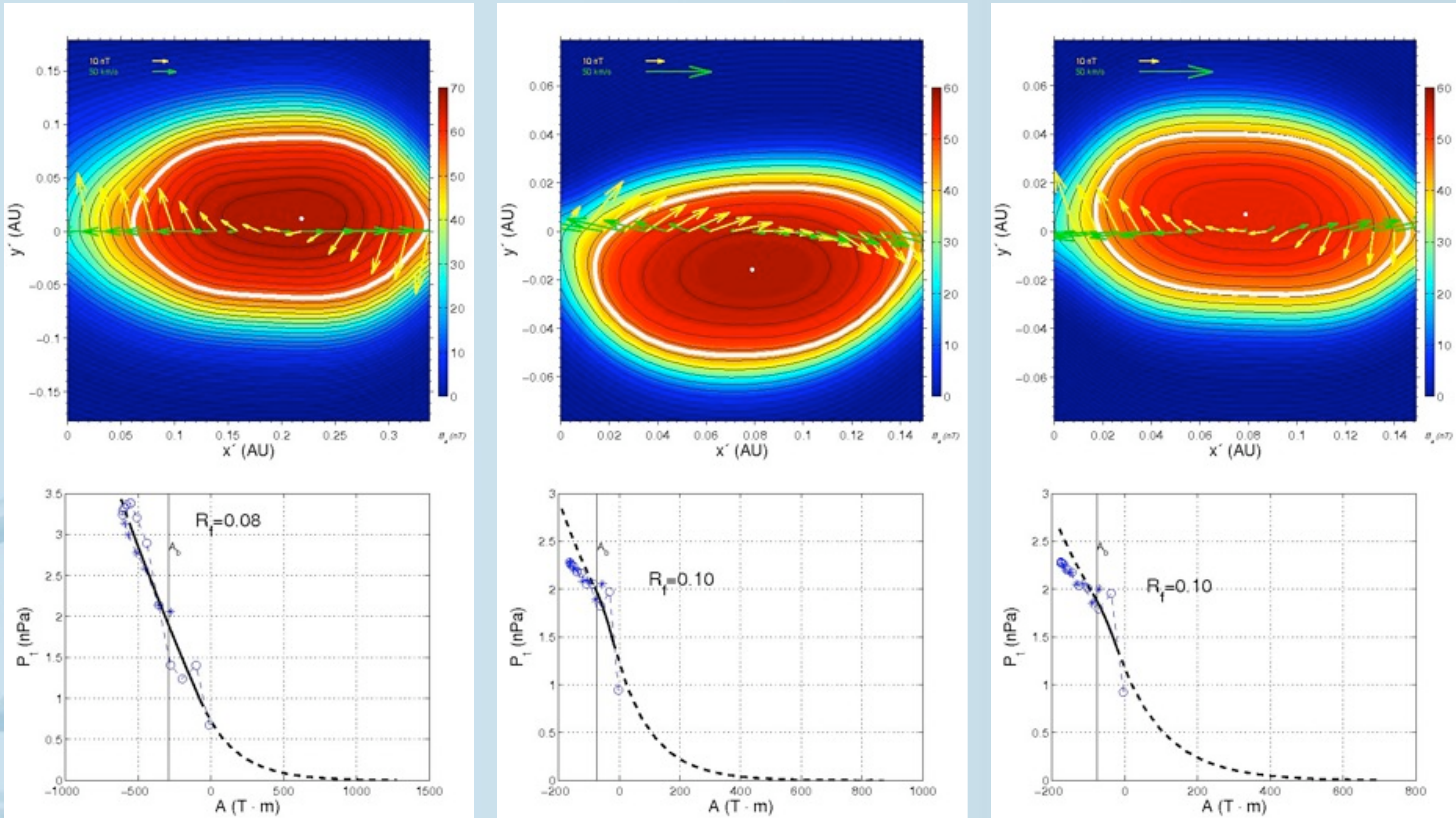
MF Reconstruction of Jacobs (PC) 15Rs:



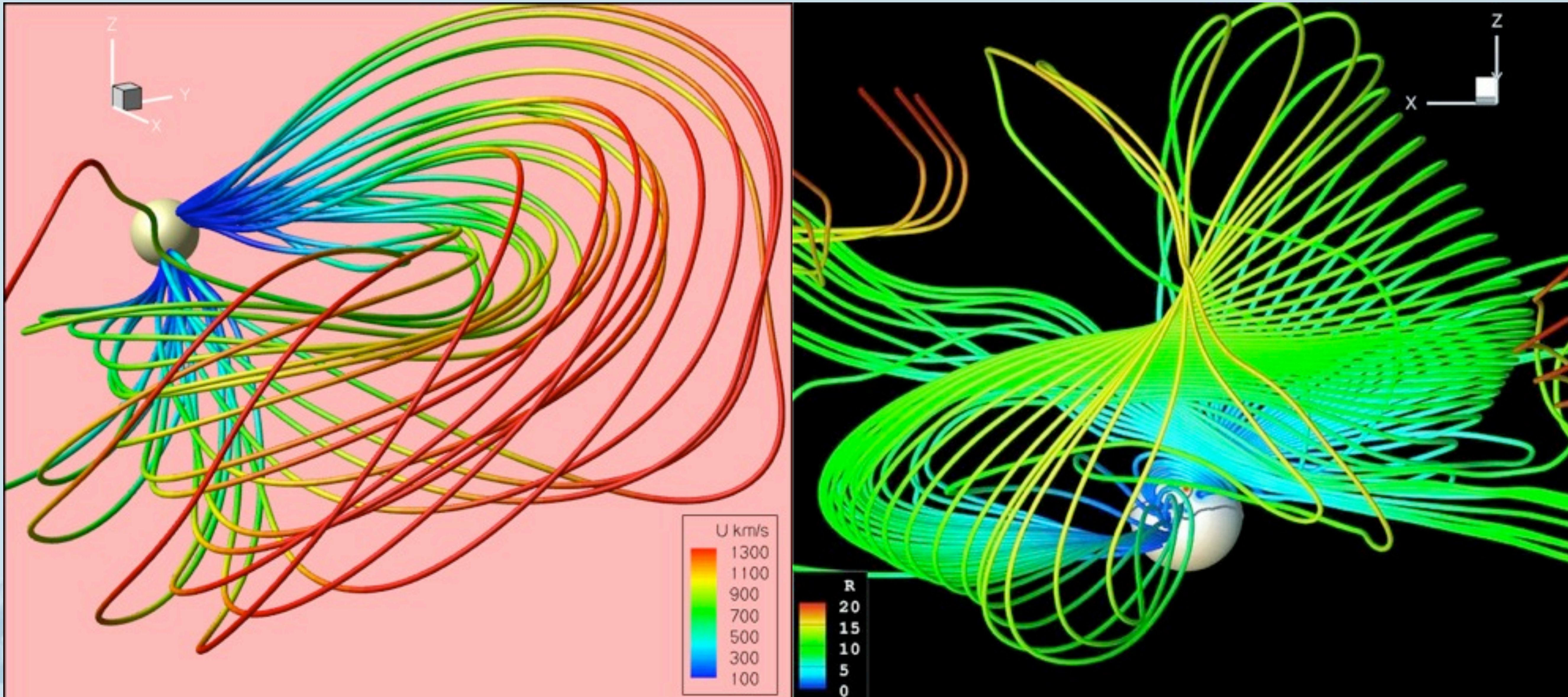
long: 70.42 and lat: -13.40 long: 121.12 and lat: -5.03 long: 61.88 and lat: -7.86

Results

MF Reconstruction of Jacobs (PC) 70RS:

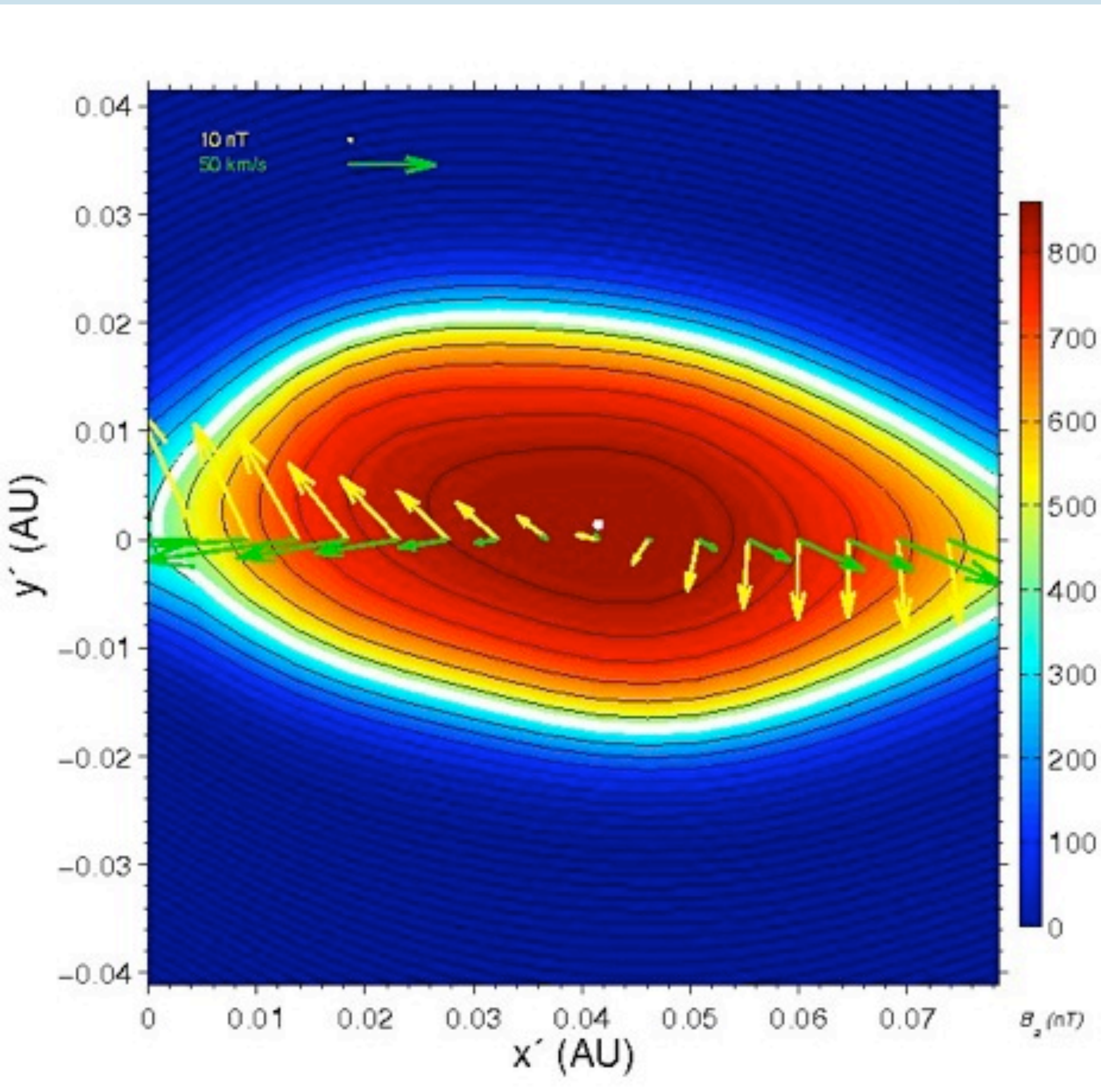


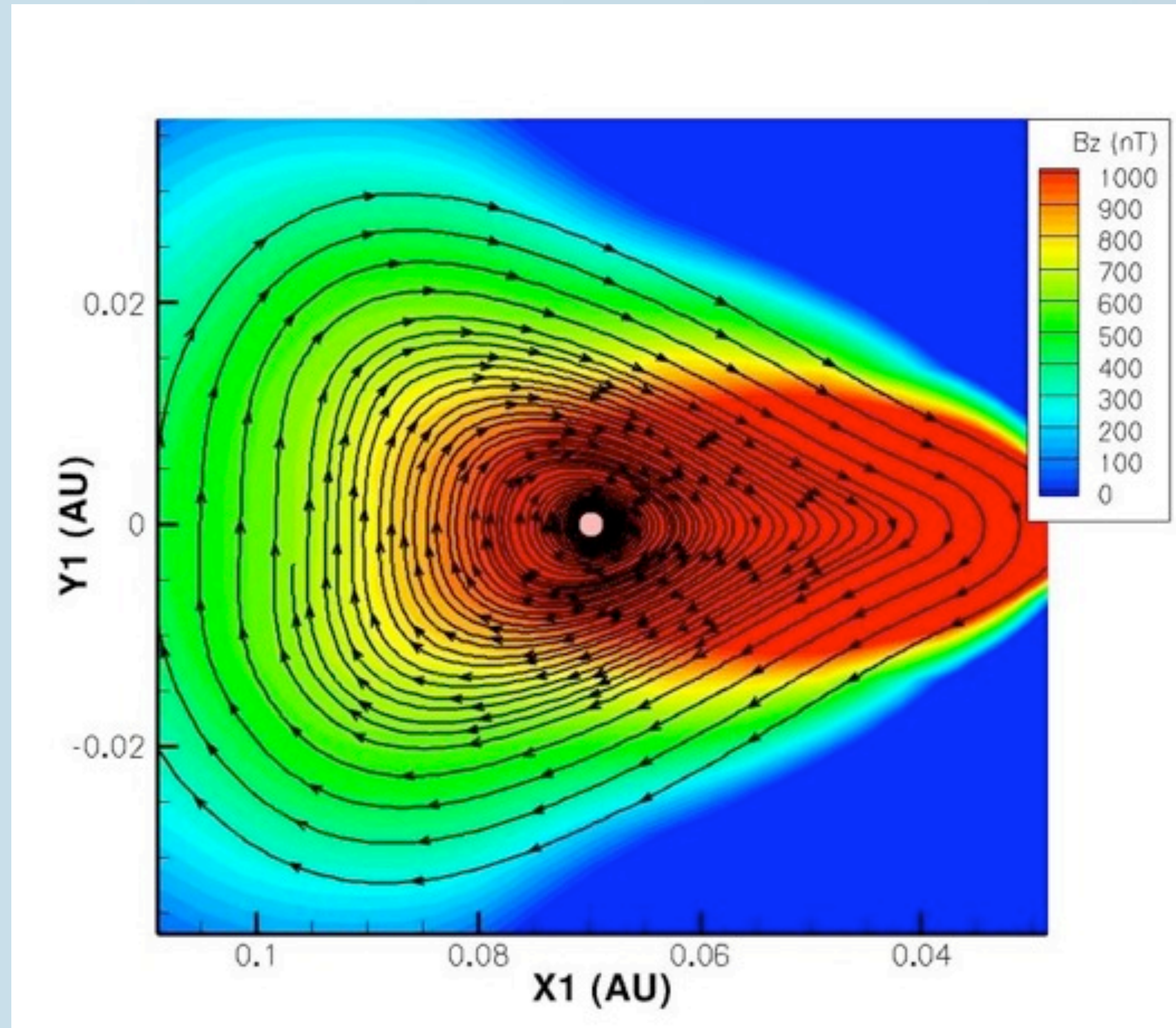
long: 95.57 and lat: -9.85 long: 86.63 and lat: -4.81 long: 81.41 and lat: -7.86)


Z
Y
X
U km/s
1300
1100
900
700
500
300
100
Z
X
R
20
15
10
5
0

Results

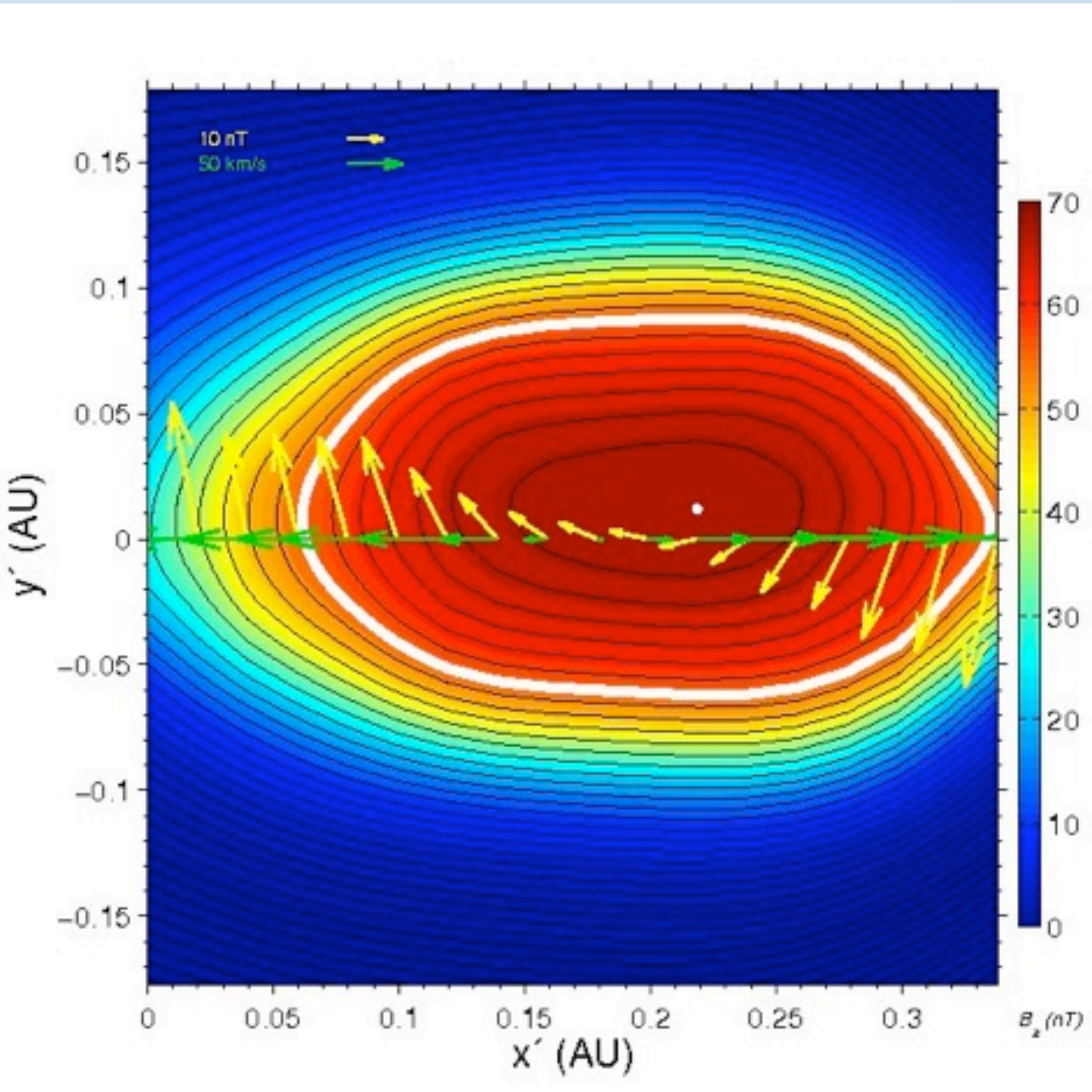
MF Reconstruction of Jacobs (PC) 15Rs:

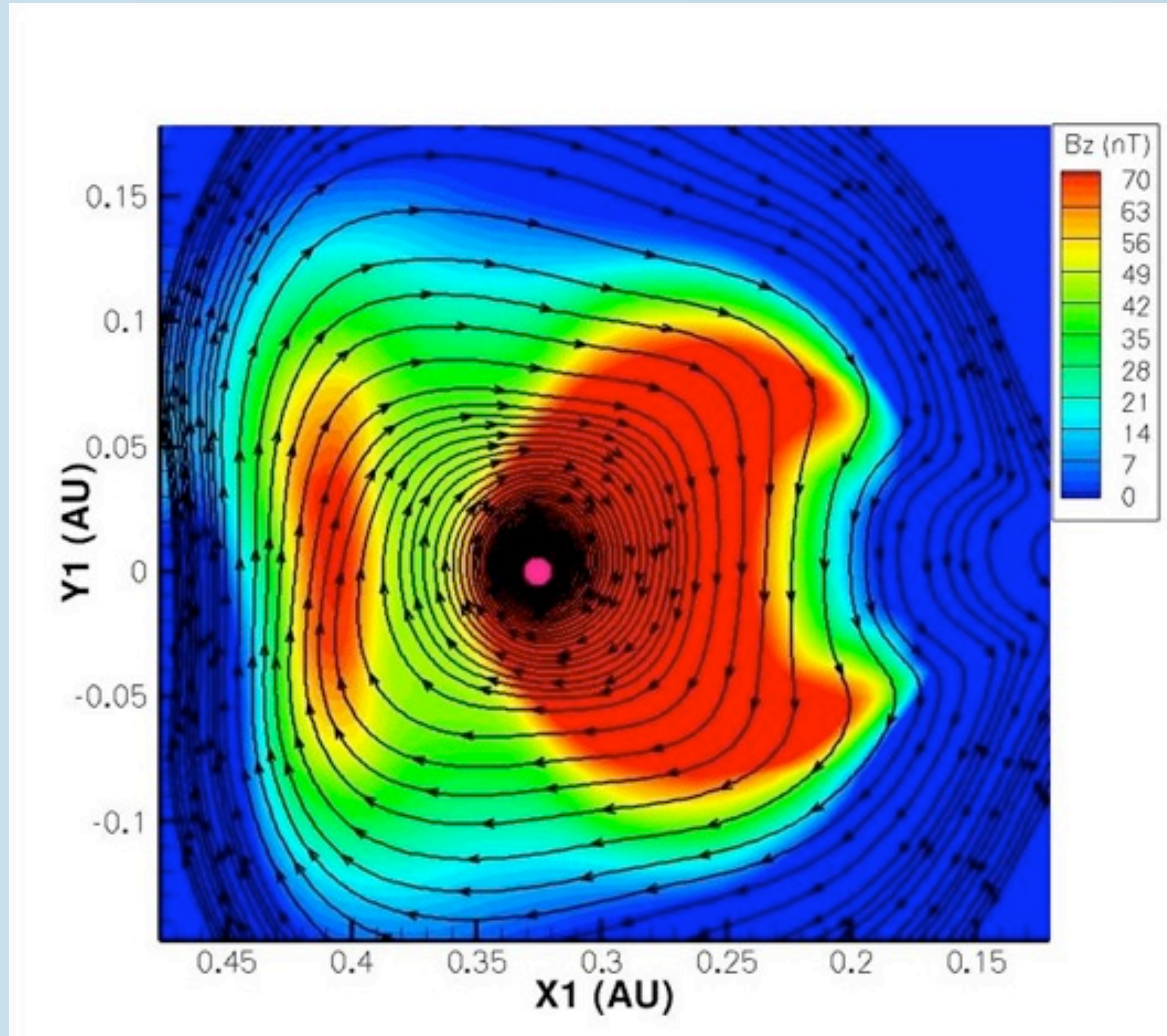




Results

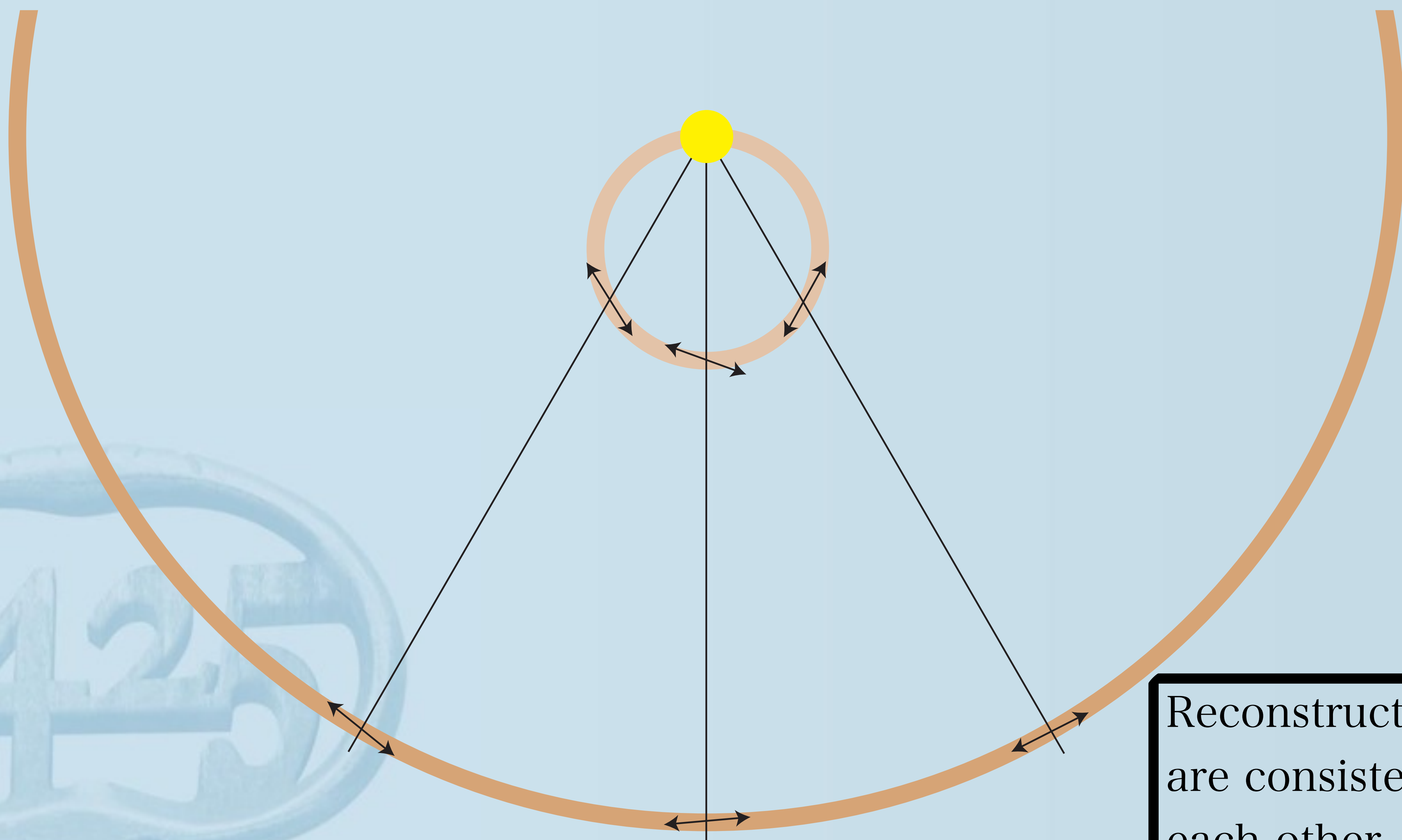
MF Reconstruction of Jacobs (PC) 70RS





The big picture

MF Reconstruction of Jacobs & Poedts (2011) 15Rs, 70Rs:



Reconstruction results are consistent with each other

ON THE INTERNAL STRUCTURE OF THE MAGNETIC FIELD IN MAGNETIC CLOUDS AND INTERPLANETARY CORONAL MASS EJECTIONS: WRITHE VERSUS TWIST

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ABSTRACT

In this study, we test the flux rope paradigm by performing a "blind" reconstruction of the magnetic field structure of a simulated interplanetary coronal mass ejection (ICME). The ICME is the result of a magneto-hydrodynamic (MHD) numerical simulation and does not exhibit much magnetic twist, but appears to have some characteristics of a magnetic cloud, due to a writhe in the magnetic field lines. We use the Grad-Shafranov technique with simulated spacecraft measurements at two different distances and compare the reconstructed magnetic field with that of the ICME in the simulation. While the reconstructed magnetic field is similar to the simulated one as seen in two dimensions, it yields a helically twisted magnetic field in three dimensions. To further verify the results, we perform the reconstruction at three different position angles at every distance point, and all results come into agreement. This work demonstrates that the current paradigm of associating magnetic clouds with flux ropes may have to be revised.

Subject headings: Sun: corona — Sun: coronal mass ejections (CMEs)

1. INTRODUCTION

Magnetic clouds (MCs), which represent about one third of interplanetary coronal mass ejections (ICMEs), are defined as plasma structures with a size of ~ 0.25 AU at 1 AU, characterized by a strong, and smoothly rotating magnetic field in a plasma of low proton temperature, and low plasma beta (Burlaga et al. 1981). If radially expanding, they exhibit a decreasing speed throughout the cloud. Other characteristics which many MCs have, such as specific charge states of heavy ions and bi-directionally streaming suprathermal (few 100s eV) electrons, especially, show that many MCs are composed of field lines connected at both ends to the Sun (Zurbuchen & Richardson 2006). To explain the characteristics of MCs, it was proposed more than 30 years ago that they consist of twisted flux ropes (Burlaga et al. 1981), and they have been described as such since then.

Numerical simulations have shown that a flux rope expanding from the solar surface will evolve during its propagation into a MC with all required plasma characteristics (Manchester et al. 2004; Roussev et al. 2003). Furthermore, Jacobs et al. (2009) successfully simulated a CME with typical characteristics of a MC, but without 2010).

Under certain assumptions, it is possible to reconstruct the 3-D magnetic field configuration of an ICME from satellite observations; the main techniques are: force-free reconstruction (Lepping et al. 1990; Lynch et al. 2003); magnetostatic reconstruction, referred as Grad-Shafranov (Hu & Sonnerup 2001; Möstl et al. 2009), torus reconstruction (Marubashi & Lepping 2007); elliptical non-force free (Hidalgo et al. 2002). These reconstructions have been tested using 2.5-D MHD simulations in Riley et al. (2004). There, the authors found that reconstruction and fitting methods have rather small errors concerning the axis orientation when the spacecraft passes close to the axis of the cloud. This conclusion was recently confirmed by a study by Vandas et al. (2010). Typically, it is expected that a MC has the lowest amount of twist at its center and the largest amount of twist at its boundaries. Using near relativistic electrons as a probing tool, Larson et al. (1997) analyzed the magnetic field line length at 1 AU for a well observed MC and they found that the field lines length (and therefore the twist) was indeed minimal in the center and maximal at the boundaries.

Conclusions:

*For each case, axes of the cloud as observed by the three different satellites are consistent with each other and descriptive of a typical shape of a MC.

*The MF reconstruction using the best code existing, has yielded a **helically twisted magnetic field**, which is a structure typical of an observed magnetic cloud.

*Magnetic clouds can be created from magnetic fields with signicant writhe and little twist.

*Thus, the current paradigm of associating magnetic clouds with twisted flux ropes has to be revised.

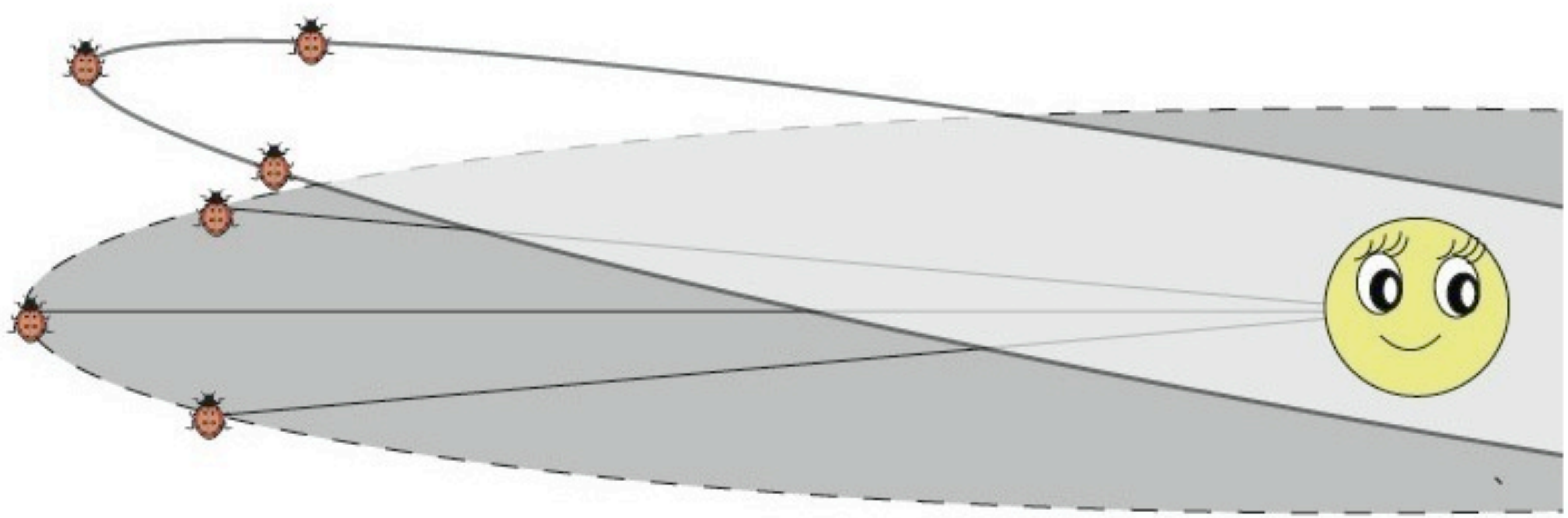
Current Work

- How can different separation and orientation help us distinguish between writhed and twisted magnetic field?

Data: Jacobs (PC) (Quadruple case)

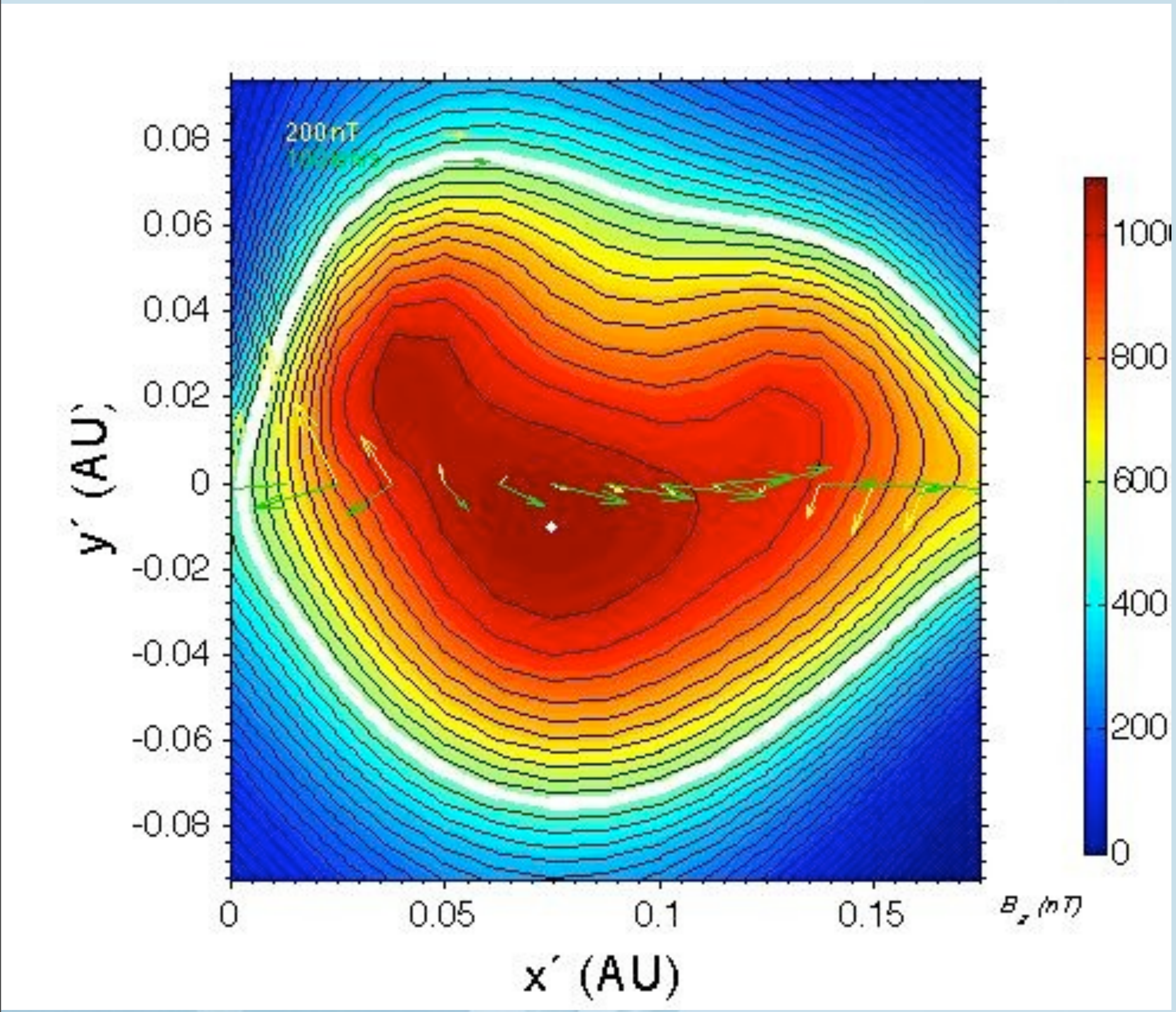
3 synthetic satellites at 15Rs

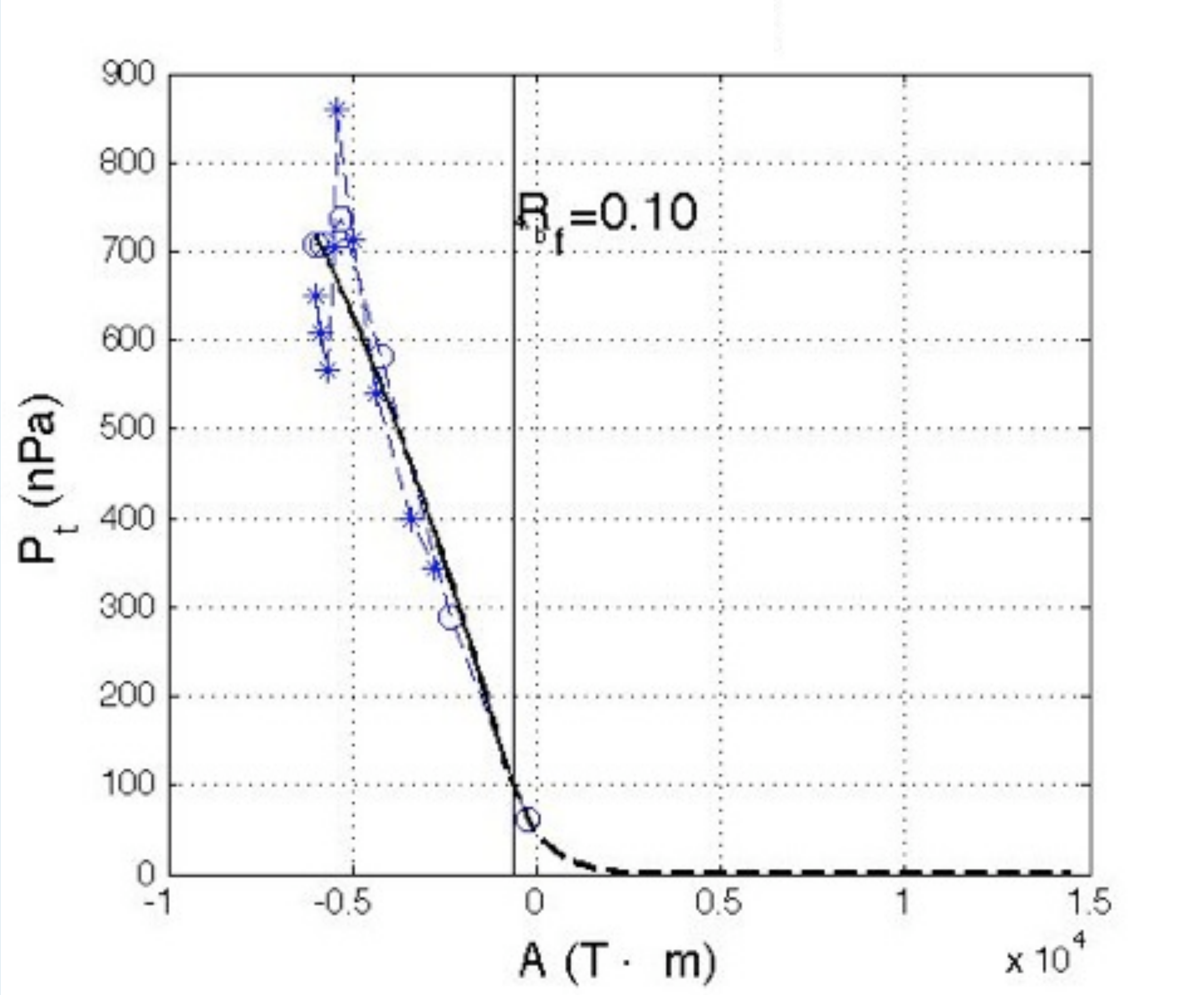
(14, 0, 5) (12, 7, 5) (12, -7, 5)



Results:

MF Reconstruction of Jacobs (Private Communication) 15Rs:

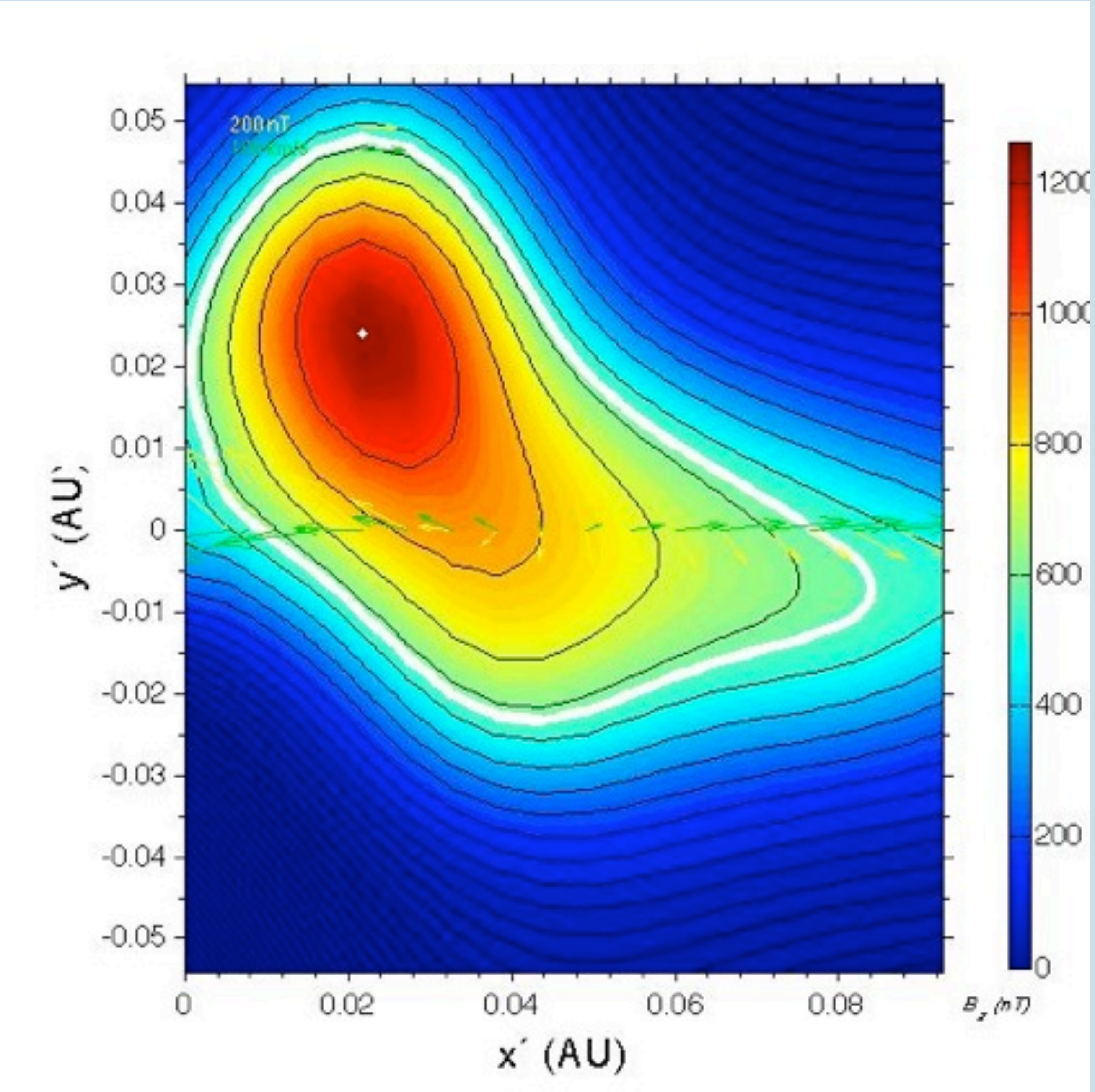


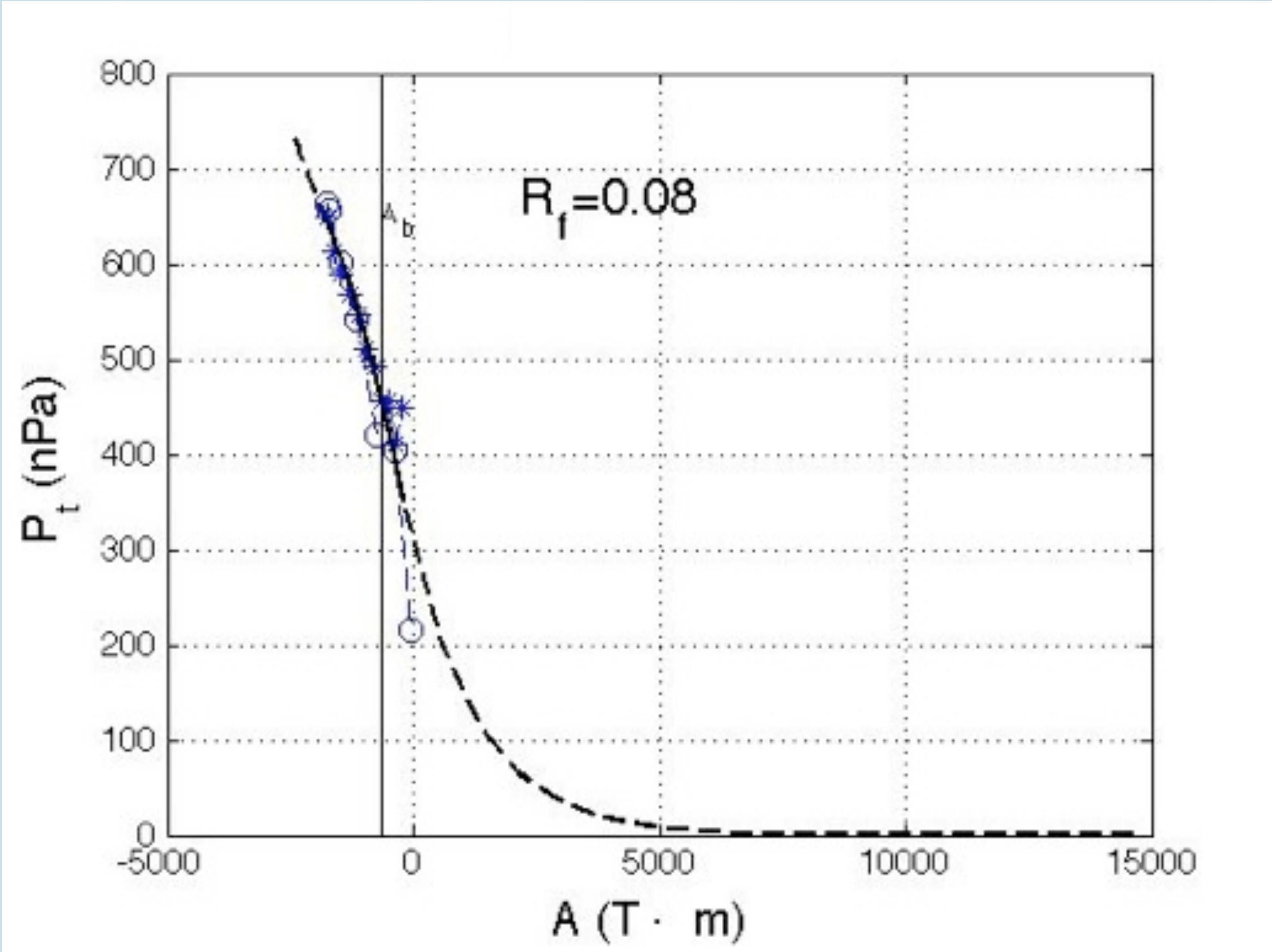


longitude: 124.37 and latitude: -14.17

Results:

MF Reconstruction of Jacobs (Private Communication) 15Rs:

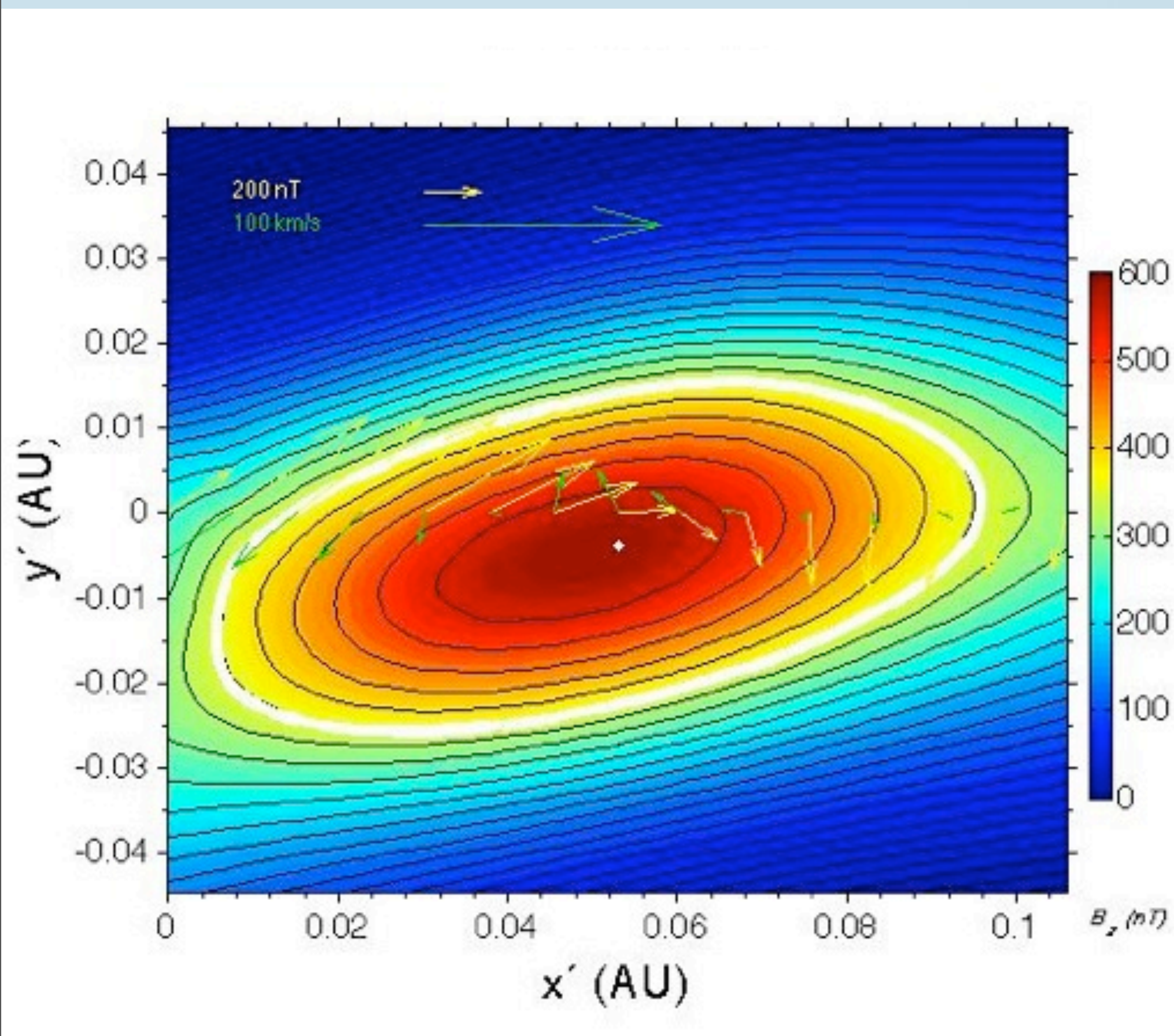


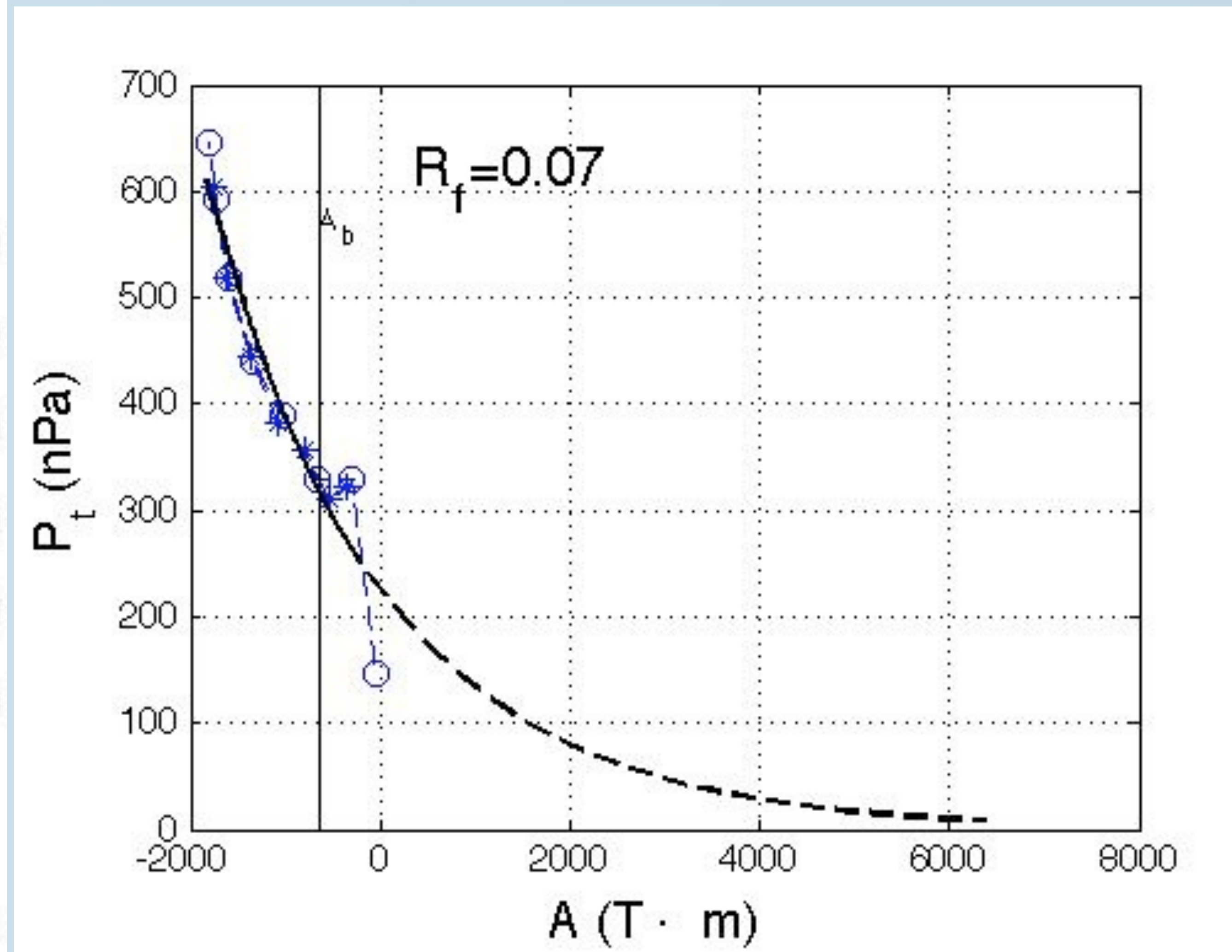


longitude: 156.82 and latitude: 38.14

Results:

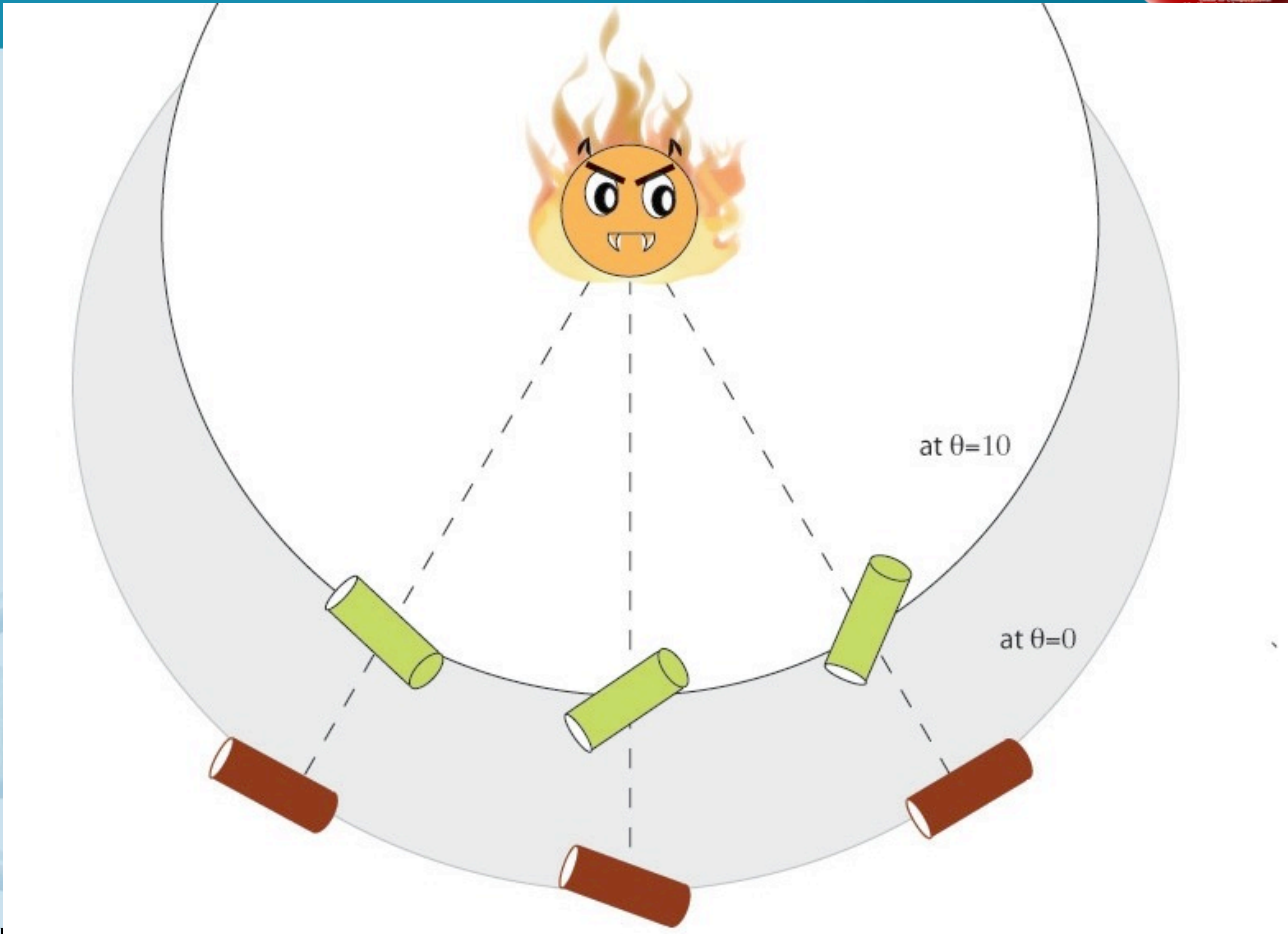
MF Reconstruction of Jacobs (Private Communication) 15Rs:



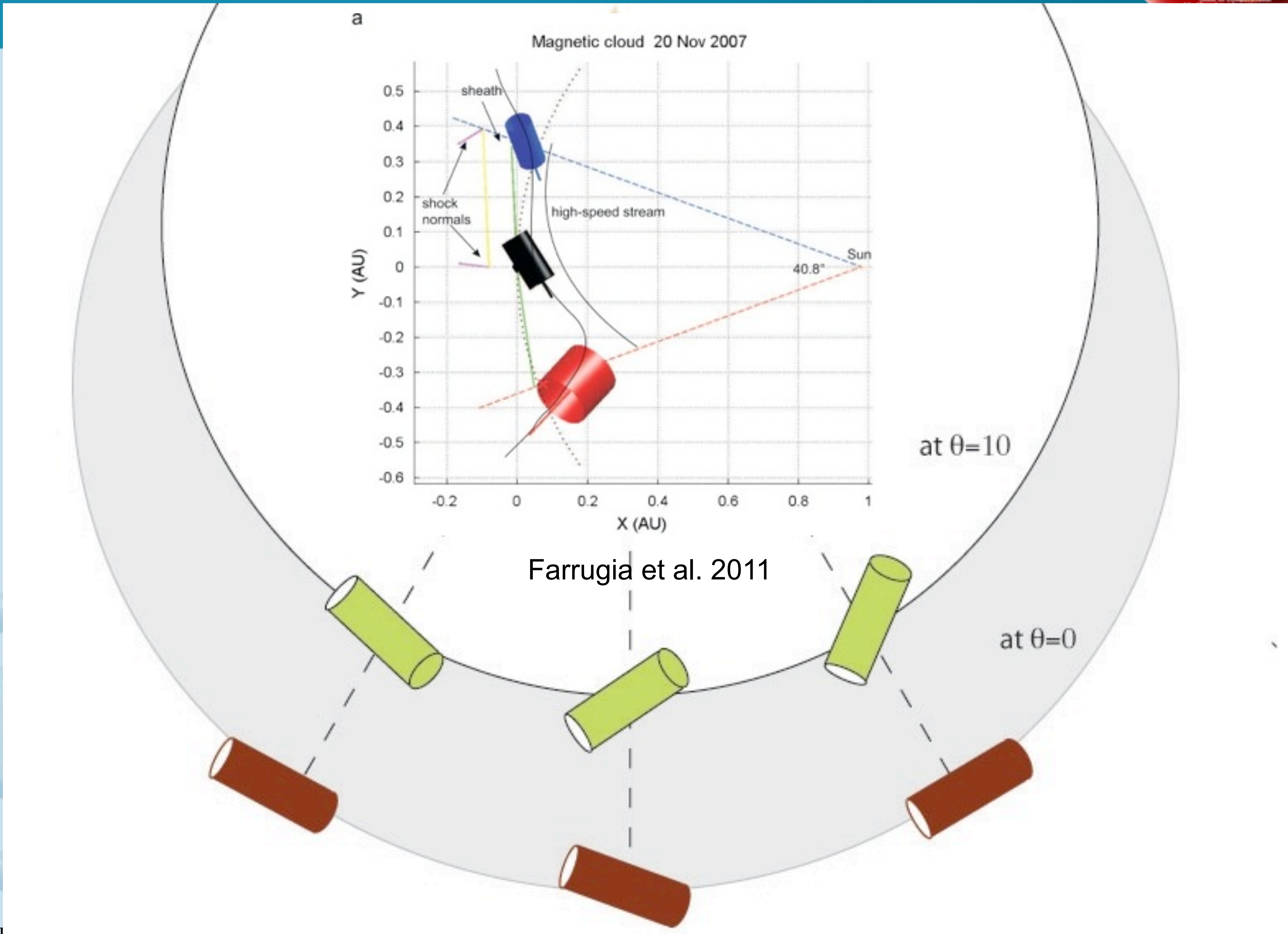


longitude: 47.37 and latitude: -24.92

Correlation..?



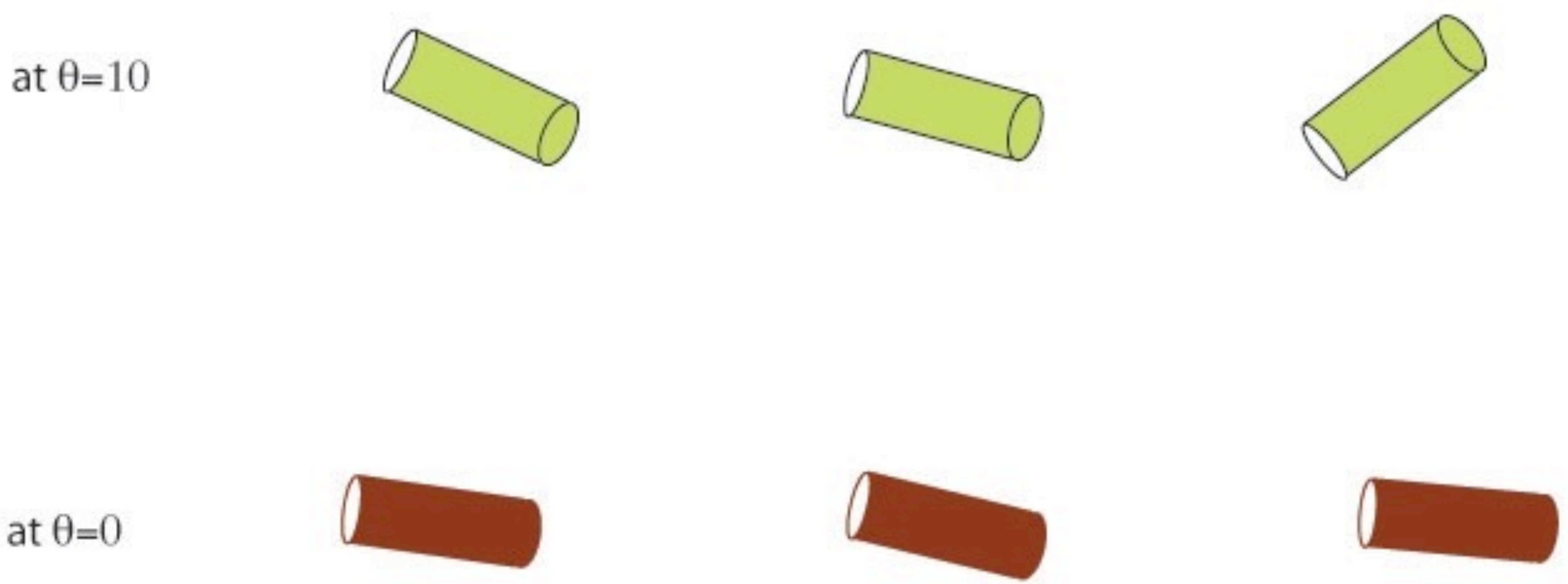
Correlation..?



Farrugia et al. 2011

Correlation..?

Latitude



Tuesday, September 6, 2011

Correlation..?

Latitude

Farrugia et al. 2011